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Stimulated Brillouin Scattering from Helium-Hydrogen Plasmas

D. H. Froula, L. Divol, D. Price, G. Gregori, E. A. Williams, and S. H. Glenzer
L-399, Lawrence Livermore National Laboratory
University of California P. O. Box 808, CA 94551, U.S.A.

An extensive study of the stimulated Brillouin scattering (SBS) in helium-hydrogen plasmas has been performed using a gas jet at the Janus Laser Facility. We observe three regions of reflectivity by varying the probe intensity from 10^{14} to 10^{16}: saturated region, linear region, and near SBS threshold region. In the linear regime, adding small amounts of H to a He plasma reduces the SBS reflectivity by a factor of 4.

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I. INTRODUCTION

Stimulated Brillouin scattering (SBS) plays an important role in the energy coupling to fusion targets at high laser energy. Current indirect-drive inertial confinement fusion (ICF) targets use low density gases to control plasma blow-off from the hohlraum walls. The fusion capsule is cooled to extremely low temperatures limiting the choice of gasses (helium) that can be used. These low-Z gas filled targets provide long-scale-length plasmas which potentially allow SBS light to be amplified to large energies. It is therefore imperative to the success of ICF to develop the ability to mitigate the backscattered light.

Large-scale-length experiments on NOVA have shown that Helium produces relatively large backscatter [?]. It has been proposed that adding small amounts of hydrogen to the helium gas could control the backscatter by adding ions moving at the ion-waves phase velocity, therefore, increasing the ion-acoustic Landau damping[1]. Experiments using CO_2 lasers have shown several orders of magnitude reduction in the SBS reflectivity when small amounts (< 10%) hydrogen is added to a pure nitrogen plasma [2].

We present an extensive study of the effects on SBS when adding hydrogen to a helium plasma. Our results indicate three regions of interest. In the saturated region ($I > 10^{15}$ W-cm^{-2}), changing the hydrogen concentration has a small effect on the SBS reflectivity. However, in the linear region ($I = 5 \times 10^{14}$ W-cm^{-2}), we measure a factor of 4 decrease in the SBS reflectivity with the addition of small amounts of hydrogen to a helium plasma. The third region, near SBS threshold ($I \sim 10^{14}$ W-cm^{-2}), shows that changing the hydrogen concentration can decrease the SBS reflectivity by an order of magnitude, but the reflectivity is sensitive to intensity. Linear gain calculations agree with our measurements and predict a maximum reflectivity for pure helium with an optimum concentration for a mixture of 70% helium and 30% hydrogen.

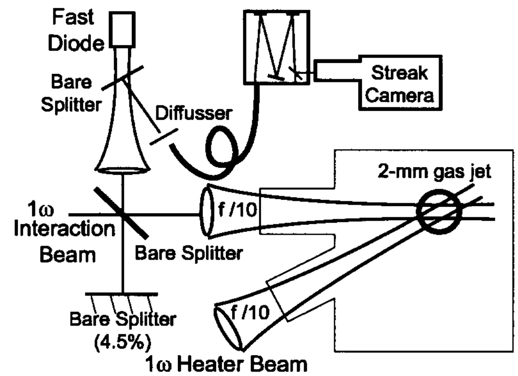

FIG. 1: Schematic of the experimental setup. Part of the incident interaction beam (4.5%) is time delayed relative to the SBS signal and focused onto the diode as an energy fiducial.

II. EXPERIMENTAL SETUP

The experiments use a two beam configuration at the Janus Laser Facility at the Lawrence Livermore National Laboratory. The plasma is produced by heating a ~ 2 mm diameter gas jet operating with a 1000 psi backing pressure which provides a density of $n_e \simeq 10^{19}$ cm^{-3}[3, 4]. The plasma was preformed using a 1ω heater beam with an intensity of $I= 10^{14}$ W-cm^{-2}. A second 1ω beam was used as an interaction beam to drive SBS with intensities between 10^{13} and 10^{15} W-cm^{-2}.

Figure 1 shows the experimental setup. The light backscattered from the plasma is collected and focused onto a fast diode and into a large chore fiber optic. The fiber is coupled to a 1-meter spectrometer; the spectrum is streaked in time (Fig. 2b). Four percent of the energy in the interaction beam is reflected into the fast diode as an energy fiducial. The SBS reflectivity was calculated by dividing the area in the signal by the area in fiducial and multiplying by 4.5%.

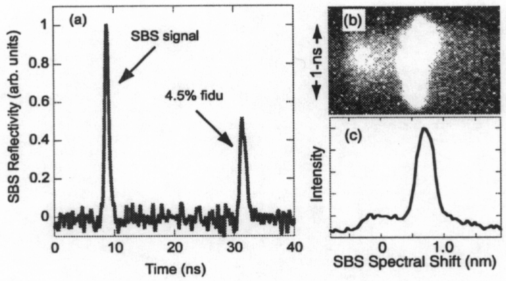

FIG. 2: (a) The SBS reflectivity is measured to be 7.5% for a pure helium plasma. The interaction beam intensity was 4×10^{14} W-cm^{-2}. (b) The streaked SBS spectrum is shown for the same conditions. (c) A 200-ps lineout was extracted from t$\simeq$ 500ps after the interaction beam is turned on.

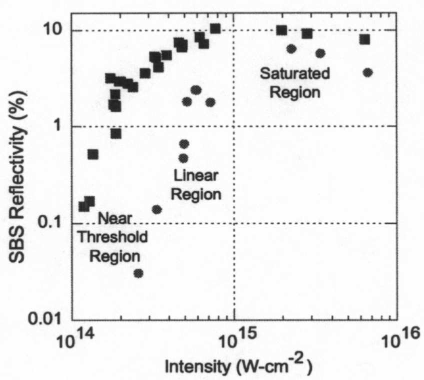

FIG. 3: Three regions of reflectivity are measured for both pure helium (squares) and pure hydrogen (circles) plasmas.

III. RESULTS

Figure 3 shows the SBS reflectivity increasing exponentially from less than 0.1% to 10% for both pure helium and pure hydrogen plasmas. This plot reveals three regions of interest for controlling the SBS backscatter instability. For intensities above 10^{15} W-cm^{-2}, the ion-acoustic waves are saturated. In this region, we measured a constant backscattered reflectivity over the entire range of helium-hydrogen mixtures. For intensities around 5×10^{14} W-cm^{-2}, Figure 3 show that the SBS instability is in the linear region.

Figure 4 shows that in the linear region (I= 5×10^{14} W-cm^{-2}), adding small amounts of hydrogen to the helium plasma has a large effect on the SBS reflectivity. The electron temperature was measured using the spectral shift in the SBS spectrum (Figure 2b); T$_e$ = 140 eV for pure helium and T$_e$ = 100 eV for pure hydrogen plasmas. The ion temperature was assumed to be T$_i$ =T$_e$/2. This decrease in the electron temperature is consistent with a decrease in the inverse Bremstrahlung as the average charge state in helium (Z=2) is decreased for pure

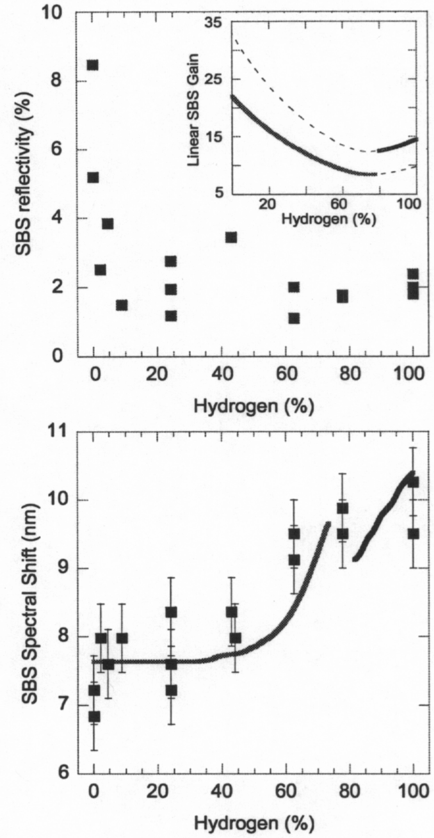

FIG. 4: (a) The SBS reflectivity drops by a factor of 4 when 10% hydrogen is added to a pure helium plasma when the SBS instability is in the linear region. (Insert) The linear gain is calculated for electron temperatures of T$_e$ = 100 eV (Top curve) and T$_e$ = 140 eV (Bottom curve). (b) The SBS spectral shift is consistent with a decreasing ion-acoustic phase velocity as hydrogen atoms are added to the helium plasma. Linear gain calculations agree with the measured spectral shift. Between 0% and 80% the measured temperature for pure helium is assumed. For concentrations above 80%, the measured temperature for pure hydrogen is assumed.

hydrogen (Z=1).

The linear gain for our conditions is plotted in Figure 4. We have assumed that the inverse Bremstrahlung is constant (pure helium-like) for mixtures of hydrogen upto 80% (Figure 4 (insert) Bottom solid line) and pure hydrogen-like for mixtures above 80% (Figure 4 (insert) Top solid line).

Figure 4b shows that the shift in the SBS spectrum is increasing as hydrogen atoms are added. This is consistent with the linear gain calculations which show an increasing ion-acoustic phase velocity over the same atomic concentration.

IV. CONCLUSIONS

We find that when the intensities are sufficient to drive the SBS instability into the saturated region, gas mixtures will have little effect on reducing the SBS reflectivity. On the other had, if the intensities are in the near threshold region, a small variation in the intensity will have a large effect on the SBS reflectivity and may be preferable in controlling SBS. For laser intensities that drive ion-acoustic waves in the linear region, we have shown that adding trace amounts of hydrogen to a helium plasma can significantly reduce the SBS reflectivity.

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